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QUARTERLY

2003 No.2

Penn State Materials Researchers Ranked Tops in Scientific Impact: iMAST's Singh Cited

Penn State was recently recognized as the most dominant university in the field of materials science internationally by the Institute for Scientific Information (ISI), an organization that monitors scientific citations worldwide and whose rankings are a respected indicator of quality across scientific disciplines.

As noted, Penn State alone accounts for nearly 5 percent of the researchers, the largest percentage to date of researchers in a given category based at a single institution. Penn State's 12 University faculty members, to include Dr. Jogender Singh, mentioned on the list, amounts to twice as many representatives as the next institution: University of Texas, Austin, with six faculty members, followed by the University of California, Santa Barbara; Stanford University; North Carolina State University; Oak Ridge National Laboratory; and Max-Planck-Institut für Metallforschung, Germany—each with five.

Dr. Jogender Singh (right), shown here with former Pennsylvania Governor Tom Ridge (and now Secretary of Homeland Defense), at a previous awards ceremony recognizing Dr. Singh's accomplishments.

Materials research is linked to virtually every field of science and technology. It is inherently interdisciplinary and includes contributions from physics, chemistry, and engineering. The discovery and development of new materials enables advances in emerging technologies such as wireless and optical communications, fuel cells, molecular electronics, and artificial organs. Materials research also can contribute to lowering the cost and enhancing the performance of more established manufacturing technologies for consumer electronics and automobiles.

Most of Penn State's strengths in materials research can be grouped into the following areas: electronic materials, devices and sensors; nanoscale science and technology; biomedical materials and devices; materials processing and manufacture; computer simulation and characterization of materials; fuel cell technology; and materials in the environment.

ISI attributes Penn State's success to its integration of materials science across a variety of colleges and departments within the university. In fiscal year 2000, the National Science Foundation ranked Penn State No. 1 for research expenditures in materials science.

ISI is the publisher of the Current Contents and Citation Index series among other scientific publications. It recognizes outstanding researchers in a variety of scientific fields. ISI uses the citation databases they have accumulated between 1981 and 1999 to track the number of citations for each paper, compiling totals of citations for each individual researcher. They identify researchers and crosscheck citations against curriculum vitae to ensure accuracy. We congratulate Dr. Singh on this prestigious honor.

Focus On Materials Processing

Report Documentation Page

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IN THIS QUARTERLY

DIRECTOR'S CORNER

Partings

It is with regret that I inform you that Steve Linder, ONR's Director of Manufacturing Technology is leaving ONR for the Missile Defense Agency. The ManTech program will miss this experienced and knowledgeable manager. I wish him well in his new duties.

Fiscal Year 2004 represents an opportunity for fresh starts at iMAST. Essentially, every iMAST project will be a new start. In line with the new strategic thrust for ManTech, iMAST will concentrate the bulk of the effort toward solving manufacturing issues concerning the next generation nuclear-powered carrier. In these efforts, I expect considerable involvement with the program office and the ship designer and builder, Northrop Grumman Newport News Shipbuilding. Several projects have been started late in Fiscal Year 03.

As this article goes to press, the budget for next year is uncertain, especially for Repair Technology, which is funded under program initiatives. With the decrease in the president's budget, funding for RepTech may be cut by over 60%. We are working on contingencies to cover this change.

The feature article in this newsletter describes thermal barrier coatings (TBCs). TBCs have been used by aircraft engine manufacturers for years. Dr Jogender Singh has led a team that has formulated a process which results in reduced thermal conductivity and increase heat reflectance, thereby allowing improved engine performance and endurance. Components coated by his process are being tested in engine tests this year. Original Equipment Manufacturers and Naval Air Systems Command are involved in the testing phase. This project was the highest rated iMAST project by the Metals Subpanel of the Joint Defense Manufacturing Technology Panel. Of note, Dr Singh was recognized by the Institute for Scientific Information for scientific impact in the field of material science (see front page).

Bob Cook

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Focus on Materials Processing

Tailored Microstructure of Zirconia and Hafnia-Based Thermal Barrier Coatings with Low Thermal Conductivity and High Hemispherical Reflectance by EB-PVD

by Jogender Singh and Douglas E. Wolfe

Zirconia and hafnia-based thermal barrier coating (TBC) materials were produced by industrial prototype electron beam-physical vapor deposition (EB-PVD). Columnar microstructure of the TBC was modified with controlled microporosity and diffuse interfaces resulting in lower thermal conductivity (20–30% depending upon microporosity volume fraction), higher thermal reflectance (15–20%) and more strain tolerance as compared with standard TBC.

Introduction

The turbine industry is continuously making an effort to increase the thermal efficiency of the engine as well as the life of turbine components under severe environmental conditions which result in oxidation and corrosion at elevated temperatures. The life of turbine components is increased by applying a thermal barrier coating composed of ZrO_2-8wt.%Y_2O_3 (8YSZ) on platinum-aluminide (Pt-Al) or MCrAlY (M= Ni, Co, Fe, or mixed combination) coated components. 8YSZ has gained widespread acceptance as a TBC material for turbine applications due to its inherent properties, and is generally applied by either the plasma spray or EB-PVD process.[1] TBC applied by EB-PVD provide advantages over the plasma spray process that include better strain tolerance, erosion-resistance, bond strength, and surface roughness.

In thermally sprayed TBC, typical grain size is approximately 1–10 µm and the coating microstructure is associated with inter-splat boundary porosity, unmelted and partially melted particles, and microcracks.[2] In EB-PVD, TBC grain sizes vary from 1–2 µm near the bond coating/TBC interface, while the TBC columnar grain length is often 100–250 µm in thickness with a high degree of crystallographic texture. The alignment of the inter-splat boundaries within thermal sprayed coatings (having typical spacings of 1–10 µm with voids and microcracks) have a more pronounced effect on thermal conductivity than with EB-PVD, reducing thermal conductivity of 8YSZ TBC from the bulk theoretical values 2.2–2.6 W/m-K to values in the range 0.7–0.9 W/m-K. However, within the first few hours of turbine engine operation, the thermal conductivity of plasma sprayed TBC can increase to 1.5 W/m-K due to high temperature sintering.

The inter-splat/ microcracks/porosity provide initial low conductivity for plasma sprayed coatings mainly because they are involved with air gaps (air has a lower thermal conductivity than zirconia.) In addition, the splat boundaries are probably few compared to grain boundaries (1 micron or so grain size) in producing significant phonon scattering. Nevertheless, the inter-splat porosity and boundaries are more effective in reducing the thermal conductivity of the material than the columnar porosity in EB-PVD TBC. If, heat resistance and greater phonon scattering associated with the plasma sprayed TBC microstructure could be applied to TBC produced by EB-PVD it could make a significant contribution in reducing the thermal conductivity. Thus, a modified microstructure of the EB-PVD TBC appears to be very promising method in lowering the thermal conductivity of the coating. It is important to distinguish the effects of phonon scattering, which decreases thermal conductivity, and photon scattering which reduces radiative heat transport. Both scattering properties are influenced by the presence of interfaces including voids, micro-porosity and grain boundaries; however, phonon scattering is effected by smaller dimension features than IR photon scattering. Efforts are underway at different laboratories in developing new TBC materials (ZrO_2-20wt.%Y_2O_3, ZrO_2-25%CeO_2 and ZrO_2-22%CeO_2-7wt.%Y_2O_3), replacing Y_2O_3

PROFILES

JOGENDER SINGH
A senior scientist with ARL Penn State, Jogender Singh's expertise includes coatings and surface modificiation of materials by various techniques, including laser and the EB-PVD process. Prior to joining Penn State, Dr. Singh worked for NASA and GE in development of new materials and coatings for aerospace applications. Dr. Singh is a Fellow of ASM, FIM, and FAAAS. He can be reached at (814) 863-9898, or by e-mail at: <jxs46@psu.edu>.

DOUG WOLFE
A research associate at Penn State's Applied Research Lab, Douglas Wolfe has been a member of the staff since 1998. Dr. Wolfe's research activities include synthesis, processing, and characterization of ceramic and metallic coatings deposited by reactive and ion beam assisted, electron beam physical vapor deposition (EB-PVD).

Dr. Wolfe is a graduate of Penn State where he received degrees in ceramic science and engineering (B.S.), material science and engineering (M.S.), and Materials (Ph.D.). Dr. Wolfe also holds a dual appointment with the Department of Materials Science and Engineering as an assistant professor. Dr. Wolfe can be reached by calling (814) 865-0316, or by e-mail at <dew125@psu.edu>.

with Sc_2O_3 within 8YSZ, and alloying 8YSZ (CeO_2, Gd_2O_3, Sm_2O_3 and Yb_2O_3), to lower the thermal conductivity.[3, 4, 5]

The main objective of the present investigation was to modify the TBC microstructure with controlled, decorated micro-porosity during EB-PVD process for reducing thermal conductivity without sacrificing other desirable properties previously discussed. The advantage of this approach is that it can be applied to other TBC materials to further reduce their thermal conductivity. Combining both properties of low thermal conductivity and high reflectance should have a dramatic impact on the performance of turbine components.

Experimental Procedure

Penn State University has a unique industrial prototype EB-PVD unit with six electron-beam guns, and 8" diameter ion source (Fig. 1). Four EB-guns can be used to evaporate coating materials and

Figure 1. Photograph of EB-PVD chamber

two EB-guns can be used to preheat the substrate to facilitate coating adhesion. In addition, the chamber has a three-ingot continuous feeding system (A, B and C as shown in Fig. 1). Overall, the main deposition chamber size is ~90cm × 90cm × 90cm. Parts can be manipulated in three dimensions on a computer-controlled rack system at a speed of 5.5–110 rpm and with a maximum load of approximately 100 Kg. Physical vapor deposition (PVD) is primarily a line-of-sight process; therefore, uniform coatings of complex parts, such as turbine blades, are produced by continuously rotating the components during the deposition process. Deposition rate and coating thickness depend on various variables including the material being deposited, deposition time, chamber pressure, electron beam operating power, and the source-to-substrate distance. PtAl and CoNiCrAlY coated test coupons were mounted on a horizontal 5.08 cm diameter stainless steel shaft which was rotating 30.5 cm above the melt pool at a speed of 7 revolutions per minute (rpm). During the ingot evaporation process, external oxygen was injected into the vapor cloud at a flow rate of 100–150 sccm in order to compensate for the loss of oxygen from the source material and to maintain the desired stochiometric TBC composition. Typical deposition chamber pressure was 1×10^{-3} Torr.

Results and Discussion

ZrO_2-8wt.% Y_2O_3

The typical microstructure of a TBC produced by EB-PVD can be divided into two zones (Fig. 2a). The inner zone (I) is the early part of multiple nucleation and subsequent growth of the columnar microstructure having large number of interfaces, grain boundaries, micro-porosity and randomly oriented grains. The thickness of the inner zone ranges from 5–10 μm and exhibits lower thermal conductivity (around 1.0 W/m-K). With increasing thickness, the structure is characterized by a high-aspect ratio columnar grain with dominant crystallographic texture. The thermal conductivity increases as the outer part of the coating becomes more crystallograhically perfect (zone II), and approaches that of bulk zirconia (2.2 W/mK). Thus, modifying TBC structures should offer the best properties available for commercial EB-PVD coatings: namely, low thermal conductivity, high strain tolerance, and good erosion resistance.

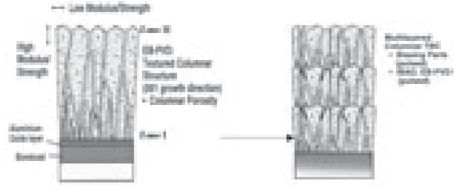

Figure 2. Schematic diagram showing (a) a typical standard vapor phase columnar microstructure and (b) modified columnar microstructure with multiple interfaces

Combination of layering at the micron level and introduction of density changes from layer to layer will significantly reduce the thermal conductivity of the coating (Fig. 2b). As mentioned earlier, layered periodicity in the coating will significantly reduce both the phonon scattering and photon transport.

Microstructural modifications within the TBC were incorporated by two approaches. The first approach used was to periodically interrupt the continuous vapor flux by translating the samples away from the vapor cloud for a short period (30–60 seconds) and then re-introducing the samples. During this interruption, the sample temperature decreased to ~700–800°C. Due to the combination of discontinuous condensation and thermal fluctuations of the sample's surface temperature during this "in and out" method, new grain formation occurs (similar concept as with inter-splat boundaries in plasma sprayed TBC). It was theorized that during nucleation and subsequent growth of the first TBC layer, the TBC would exhibit more randomly oriented grains (i.e., similar to zone I of Fig. 2a, which generally occurs during standard single layer 8YSZ deposition). After the interruption, subsequent nucleation of the second layer (on the previous grown textured layer—zone II) will again exhibit crystallographic texture similar to zone I resulting in more random texturing. As additional material deposits on the sample, the grains grow with the zone II structure forming a sharp interface between the new and previously formed grains (Fig. 3). Due to the columnar grain faceted surface morphology, additional microporosity develops at or near each interface of the next nucleating TBC layer. The interfacial volume fraction of the distinct interfaces and degree of microporosity depends on the periodicity or total number of layers. This concept is referred to as the "in and out" approach. By increasing the total number of layers, the volume fraction of randomly oriented grains (near zone I of each layer) increases and as anticipated, was found to be less crystallographically

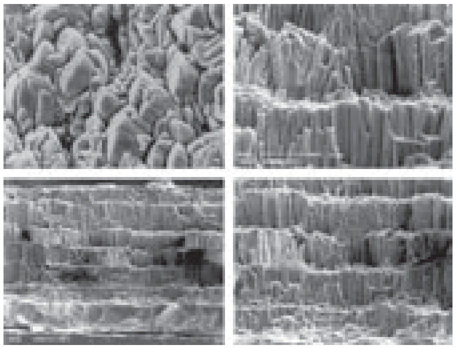

Figure 3. SEM micrographs showing a fracture surface of 8YSZ produced by EB-PVD using "in and out" method exhibiting multiple sharp interfaces

textured when compared to a standard single-layered TBC. In general, a standard single layered 8YSZ coating shows a strong (002) crystallographic texture. Although layered TBC shows a (002) crystallographic orientation, observance of additional high index planes are the result of more randomly oriented grains.[1] Subsequent growth of these grains during deposition will change its crystallographic growth orientation, and is believed to be the result of the competition between strain energy and surface free energy.

The second approach used was to periodically interrupt the continuous flux of the vapor cloud by using a "shutter" mechanism. It is important to mention here that the temperature of the substrate remained constant during the deposition process (whereas it decreased to 700–800°C during the "in and out" method), but discontinuous vapor condensation still occurred. During this interruption period, it is believed that the surface mobility of the condensed species contribute towards the surface relaxation of the deposited coating. As the vapor flux is prevented from condensing on the surface, the surface atoms have enough time, energy and surface mobility to diffuse to regions of lower energy. As a result, the surface strains change resulting in more phonon scattering due to different strain energy fields, thus resulting in lower thermal conductivity. When the shutter is opened, the new flux deposits on a slightly different strained surface. This newly strained surface results in a very diffuse interface which may contain microporosity and intracolumnar morphology differences than that of a standard single layered 8YSZ. By restricting the vapor flux from depositing on the surface, the initial atoms depositing on this newly strained surface start to condense in regions of lower energy until rapid condensation occurs which leads to island coalescence and again different strain energy fields. During the initial deposition, atoms form islands and grow until the flux rapidly increases resulting in grain coalescence producing microporosity. However, when viewed from the top surface, the grain size does not change, but the intracolumnar microstructure (i.e., microporosity and morphology) is believed to be altered (Fig. 4). Microporosity was not detected by SEM, but additional characterization is underway to confirm this analysis. Since there is no temperature change (just a disruption of the vapor flux), the long high-aspect ratio columnar grains continue to grow to the total coating thickness, similar to standard single layer 8YSZ. Comparison with a standard 8YSZ shows no distinct differences in macrostructure. Since the growth orientation of the new flux remains the same as the underlying grain, similar crystallographic texture occurs (not shown), but can vary depending on the total number of "shuttered" layers. The interface between the condensed flux and the newly arrived flux is diffuse (i.e., no sharp distinct interface) which results in microporosity near the interface. Such microstructural modifications will have an impact on the thermal conductivity. This theory was confirmed by measuring the thermal conductivity and hemispherical reflectance of the layered TBC deposited by both approaches.

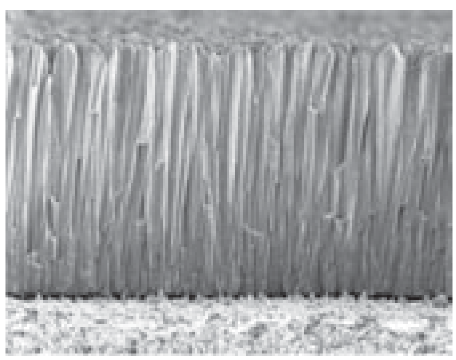

Figure 4. SEM micrographs showing a fracture surface of 8YSZ deposited by EB-PVD having 40-layers using the "shutter" method

Fig. 5a shows comparative thermal conductivity of a standard single layered 8YSZ, layered TBC with diffuse interface produced by "shutter" method, and layered TBC with sharp interface produced by "in and out" concept. The thermal conductivity of the 10-layered TBC (shutter) is comparable with the 10-layered TBC produced by "in and out". In order to establish a relationship between the thermal conductivity as a function of total number of TBC layers, additional TBC coated samples were produced using the shutter concept. It was established that the thermal conductivity decreased linearly as a function of increasing number of layers as shown in Fig. 5b. This confirms the theory that periodic interruption of the

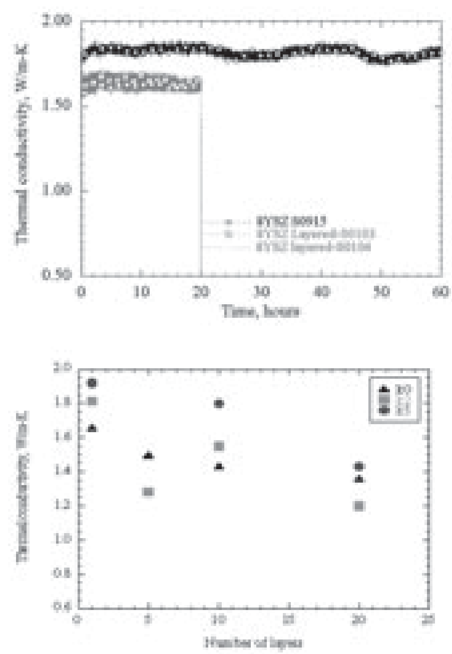

Figure 5. Thermal conductivity of EB-PVD 8YSZ coatings determined by a steady state laser heat flux technique at 1316°C: (a) thermal conductivity as a function of testing time for coatings produced by: standard continuous evaporation, flux interruption by "shutter", and flux interruption by "in and out" concept,; (b) thermal conductivity of EB-PVD 8YSZ coatings as a function of total number of layers produced by the "shutter" method measured at various stages of testing, K0-as deposited, k2 after 2h testing and k5 after 5 h testing

incoming flux by "shutter" method results in lower thermal conductivity as compared to a standard 8YSZ.

In addition to decreasing thermal conductivity, the diffuse interfaces should also affect the hemispherical reflectance of the coating and therefore reduce radiative heat transport through the TBC. As shown in Fig. 6, the coating reflectance increased as function of total number of layers, from ~35% (1-layer) to 45% (20-layers) at 1 µm wavelength. This suggests that more heat will be reflected from the coatings as the number of layers increases within the TBC. Reflectance of the "in and out" layered TBC was increased from ~ 40% to 55% as the total number of sharp interfaces increased from 10 to 40 at 1 µm wavelength.

The layering concept has

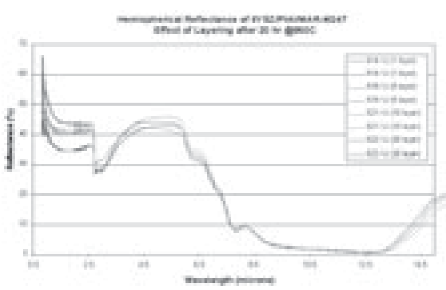

Figure 6. Hemispherical reflectance of layered (1, 5, 10, and 20 total layers) 8YSZ produced by "shutter" method after thermal exposure at 950°C for 20 hours

opened an opportunity in engineering TBC with desired higher reflectance and lower thermal conductive properties through microstructural modifications. The layering concept was extended to HfO_2-base alloyed ceramic coatings as well as engineering new TBC materials in exhibiting high reflectance properties over a wide wavelength range.

HFO_2-BASED CERAMIC COATINGS

The effort was undertaken to define the process window in applying HfO_2-40wt.%ZrO_2-20wt.%Y_2O_3 and HfO_2–27wt.%Y_2O_3 coatings on Pt-aluminide bond coated Rene N5 buttons. Coatings were applied using the standard process parameters used for 8YSZ. The HfO_2-40 wt.% ZrO_2-20wt.%Y_2O_3 coatings exhibited relatively dense columnar grained microstructure as compared with 8YSZ (not shown). HfO_2-27wt.%Y_2O_3 coatings were also deposited under the similar processing parameters. The coating exhibited an even relatively denser coating in comparison with the HfO_2-40wt.%ZrO_2-20wt.%Y_2O_3. Xrd showed that both HfO_2-27wt.%Y_2O_3 and HfO_2-40wt.% ZrO_2-20wt.%Y_2O_3 have a cubic phase structure. Texturing of the cubic HfO_2-27wt.%Y_2O_3 coating growth changed as substrate temperature was increased from 1000 to 1100°C determined by Xrd.

The thermal conductivity of the HfO_2-40wt.%ZrO_2-20wt.%Y_2O_3 and HfO_2-27wt.%Y_2O_3 coatings were measured by the steady-state CO_2 laser technique. As shown in Fig. 7a, the thermal conductivity of HfO_2-27wt.% Y_2O_3 was found to be the lowest (1.1 W/m-K). HfO_2-27 wt.%Y_2O_3 exhibited relatively low conductivity rate increase at high temperature due to its good sintering resistance as compared with ZrO_2-8wt.%Y_2O_3. In order to further reduce the thermal conductivity of HfO_2 -27wt.%Y_2O_3, the layering concept was explored. The thermal conductivity of HfO_2-27wt.%Y_2O_3 was further reduced with increasing total number of layers (Fig. 7b). Similar to the 8YSZ reflectance data, layering the HfO_2-27wt.%Y_2O_3 coatings also exhibited an increase in hemispherical reflectance from 50% to 65% at 1 µm wavelength. These findings reconfirm previous findings with 8YSZ, indicating that these are microstructural effects (and not compositional) which can be adapted to other TBC systems easily.

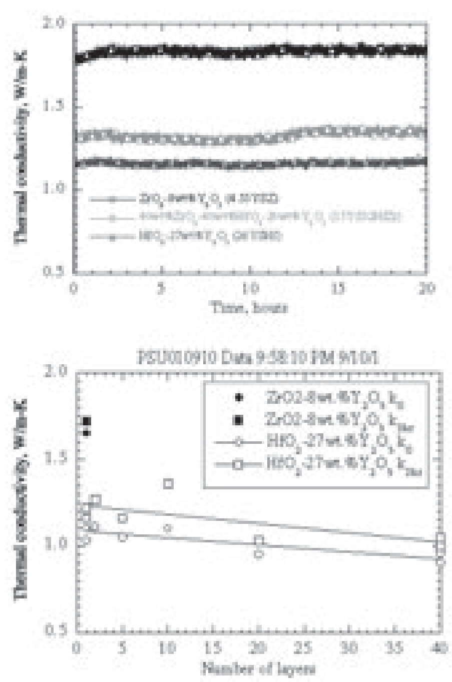

Figure 7. (a) Comparative thermal conductivity of EB-PVD 8YSZ, HfO_2-40wt.%ZrO_2-20wt.% Y_2O_3 and HfO_2-27wt.%Y_2O_3 coatings as a function of test time and (b) thermal conductivity of EB-PVD HfO_2-27wt.%Y_2O_3 coatings as a function of number of layers produced by "shutter" method

Summary

This research paper has demonstrated that tailoring the microstructure of TBC will allow engineering of potential new TBC materials with lower thermal conductivity and higher thermal reflectance properties. This concept can be extended to other TBC materials. Major achievements of the present findings are summarized below:

- Layered TBC structure exhibited reduction in thermal conductivity by 15–30% depending upon the volume fraction of micro-porosity.
- Layered TBC exhibited increase in reflectance by 12–15%.
- The HfO_2-27wt.%Y_2O_3 coating exhibited relatively low thermal conductivity, low rate of conductivity increase, and good sintering resistance as compare with ZrO_2-8wt.%Y_2O_3 and HfO_2-40wt.%ZrO_2-27wt.%Y_2O_3.

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ARL project leader, Leo Schneider, briefs Congressman John Murtha (center) on the lab's Anti-Torpedo Torpedo (ATT), while Bob Cook, iMAST director (left), and ARL associate director, Tom Donnellan (right) look on.

Commerce Showcase

iMAST recently participated in the annual Johnstown (PA) Showcase for Commerce forum in Cambria County, PA. The showcase once again provided an opportunity for business, government, and research organizations alike to showcase advanced technologies being developed throughout the local region. Industry support by United Defense, Raytheon, DRS Technologies, General Dynamics and The Boeing Company attest to the quality level of participation. Forums like Johnstown's Showcase aid technological innovation efforts by bringing together the necessary ingredients to transfer technology into both civilian and DoD manufacturing sectors. Opportunities like this showcase provide smaller organizations a chance to interface with key players in the R&D world, as well as prime contractors and DoD customers. In many cases, out-of-the-box thinking emerges as dialog develops between researcher, manufacturers, and customers. The annual Johnstown Showcase for Commerce is scheduled again for next spring. Check our calendar of events for future information.

iMAST director, Bob Cook, discusses program effort with TechTrends exhibit booth visitor.

Tech Trends 2003

iMAST, as part of an ARL Penn State contingent, recently participated in Tech Trends 2003. Tech Trends is a forum for interested parties within the Mid-Atlantic states who want to learn about federal research and development programs in such diverse areas as electronics and computers, medical and pharmaceutical research, aeronautics, space, national defense, security, energy and environmental technologies. The conference provides opportunities for researchers and executives to engage in dialog with representatives from government research and development agencies, as well as major R&D corporations. Initiated by Pennsylvania Congressman Curt Weldon, the conference continues to grow annually.

This year's theme "Global Gateway for Science and Technology" was hosted in Wilmington, Delaware. Under the organizational leadership of NDIA, congressional delegations from Pennsylvania, New Jersey, Delaware, and Maryland, hosted two days of valuable conference agenda. Dr. Ed Liszka, Director of Penn State's Applied Research Laboratory, served as panelist. Corporate co-sponsors included Boeing, Northrup Grumman, American Competitiveness Institute, SAIC, and Lockheed Martin. Keynote speakers featured former Delaware Governor Pete DuPont, and Deputy Assistant Secretary of Defense for Research and Technology, Dr. Michael Andrews. Next year's Tech Trends will be held in Pittsburgh during April.

ARL's Bob Walter (left) talks with Mr. Jerry Irvine, a Public Affairs Officer with the U.S. Army's Aviation & Missile Command.

Army Armor Conference

The annual U.S. Army Armor Conference, sponsored by The Defense Logistics Information Service (DLIS), was recently held at Ft. Knox, KY. ARL's Complex Systems Monitoring Department attended the event, profiling ARL capabilities within the Ground Combat and Combat Service Support Vehicle Technology Group. With approximately 80 vendors and 1000 attendees, the conference provided an excellent opportunity to acquaint the armor vehicle community with ARL's capabilities and current armor vehicle-related programs. The conference also provided an opportunity for ARL Penn State engineers to meet and learn about challenges facing the armor community. ARL is currently working on a number of armor vehicle issues which include: reduced weight road wheels, ballistic tolerance evaluation, noise abatement, applique armor refurbishment, and complex systems monitoring. For more information about the conference and ARL's systems monitoring effort, contact Jeff Banks at (814) 863-3859 or e-mail him <jcb242@psu.edu>.

CALENDAR OF EVENTS

9–10 Sep.	Materials & Manufacturing Advisory Board Meeting		State College, PA
15 Sep.	MarCorSysCom Industry Day		Crystal City, VA
15–17 Sep.	AFA Expo		Washington, D.C.
16–18 Sep.	Marine Corps League Expo	*visit the iMAST booth*	Quantico, VA
22–25 Sep.	NDIA Joint Undersea Warfare Conference		Groton, CT
23–24 Sep.	NDIA Combat Vehicle Conference		Ft. Knox, KY
5–8 Oct.	AGMA Gear Expo 2003		Columbus, OH
6–8 Oct.	AUSA Expo		Washington, D.C.
8–9 Oct.	Naval Institute Warfare Exposition		Virginia Beach, VA
14–15 Oct.	NCEMT Friction Stir Welding Conference		Johnstown, PA
17–20 Oct.	World Maritime Technology Conference		San Francisco, CA
20–23 Oct.	Expeditionary Warfare Conference		Panama City, FL
27–30 Oct.	DoD Maintenance Symposium 2003		King of Prussia, PA
17–20 Nov.	ASME Mechanical Engineering Congress		Washington, D.C.
18–19 Nov.	Fleet Maintenance Symposium		Virginia Beach, VA
1–4 Dec.	Defense Manufacturing Conference 2003	*visit the iMAST booth*	Washington, D.C.
2004			
Jan. TBA	ShipTech	*visit the iMAST booth*	TBA
3–5 Feb.	U.S. Naval Institute West 2004 Technology Expo		San Diego, CA
Apr. TBA	Navy League Expo	*visit the iMAST booth*	Washington, D.C.
Apr. TBA	TechTrends 2004	*visit the iMAST booth*	Pittsburgh, PA
May TBA	Johnstown Showcase for Commerce	*visit the iMAST booth*	Johnstown, PA
May TBA	USCG Innovation Expo		Baltimore, MD

Quotable

"The [U.S.] fleet is going to continue to decline. It has already been locked in a 250-ship Navy. It's just a matter of time."
—Cynthia Brown, President of the American Shipbuilding Association

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